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# A RAPID METHOD FOR FINDING THE VOLUME AND DENSITY OF MUSKMELON FRUITS [1]

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## INTRODUCTION

Size or volume is an important factor to be considered in variety improvement of muskmelons. The volume-weight or ratio of weight to volume, the density index, is a satisfactory indication of the amount of edible pulp—one of the important factors that determine market value. A density index obtained by cutting the fruits and classifying them by inspection is not always sufficiently accurate. Moreover, such treatment renders the fruits unsuitable for further handling or storage. To measure the volume of a large number of melons by xylometric methods is laborious and time consuming. The method outlined in this report combines features which might simplify the measurement of volumes and therefore density. The procedure is rapid and sufficiently accurate, with the advantage that the major part of the work can be done from the records, thereby facilitating work on a highly perishable fruit.

## MATERIALS AND METHODS

Measurements from 426 muskmelon fruits that varied in size, shape, and genetic origin were used to determine the necessary data for the preparation of the muskmelon volume alinement chart. In addition, the longitudinal cross sections of 80 melons were graphically analyzed to compare the shape of muskmelons with the shape of geometrical solids of revolution generated by the circle and ellipse. Figure 1 shows the frequency distributions of the diameters, volumes, and form classes of the 426 melons. The approximate ranges of the different measurements are as follows: The smallest fruit was 8 cm. in diameter and 9 cm. in length; the largest approximately 20 cm. in diameter and 23 cm. in length. The volumes varied from 400 to over 4,500 cc., and the shape or form from very elongated fruits with a diameter 60 percent of the length to very flat melons with the diameter over 115 percent of the length. However, as shown in the frequency distributions, melons with this extreme shape were rare.

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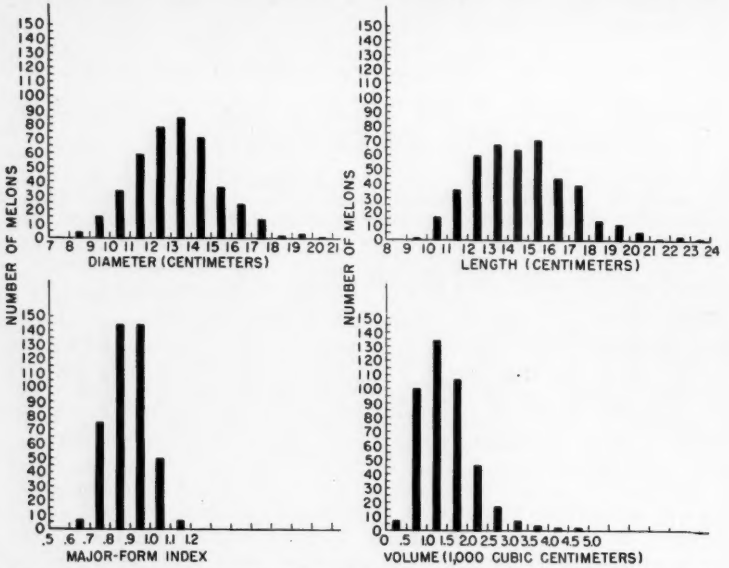


FIGURE 1.—Frequency distributions of the diameter, length, major-form index, and volume of 426 muskmelon fruits.

Most of the fruits came from strains grown on experimental breeding plots. A few were purchased locally, including Honeydew and Mildew Resistant 45 types not commonly grown in Minnesota.

It is thought that the sample adequately covers muskmelon fruit variations in size and shape, with the possible exception of very flat types which are relatively rare. Nevertheless, before applying the results to other melon populations, a test sample should be checked by a method suggested later.

The length and diameter of each melon were measured to the nearest one-tenth centimeter by the caliper shown in figure 2. To obtain an accurate average diameter, the largest and smallest diameters were measured and averaged. The volume was determined to the nearest cubic centimeter by submerging each fruit in a tank filled to an overflow tube and measuring the volume of water displaced. Weights were determined to the nearest gram on a beam balance.

In order to ascertain whether the fundamental factors that determine volume vary with the general shape of fruits, a numerical index of shape or form was necessary. For this purpose, the ratio of the diameter to the length was used as an index of general form and called the major-form index.[3] This was computed for all fruits. By means of this index, the melons were arbitrarily classified into form or shape classes of 0.675, 0.775, etc. The form factor, $\frac{V}{D^2L}$, or ratio of the actual volume to the product of the square of the diameter, $D^2$, times the length, $L$, was computed for each of the 426 fruits.

[3] The ellipticity or $\left(1-\frac{d}{L}\right)$ might have been used as an alternate index of form.

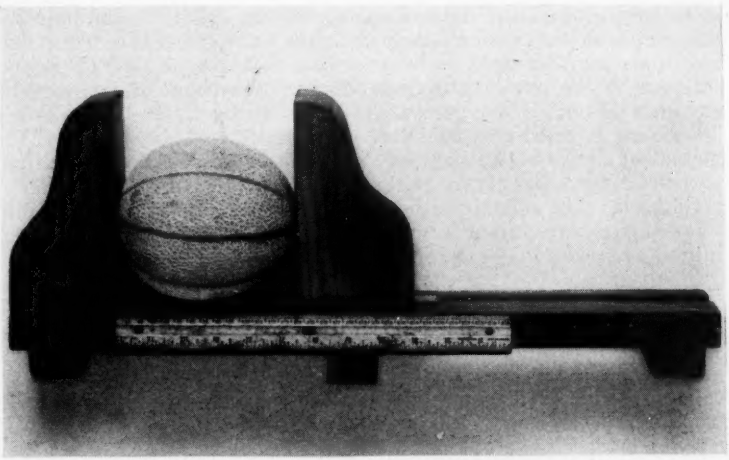

FIGURE 2.—Caliper used to measure the diameter and length of muskmelon fruits.

To study the actual shape of the muskmelons in order to compare them with the shape and volume of geometrical solids of revolution, diagrams of the major or longitudinal cross section through the blossom and stem ends were made by halving 80 melons and tracing the cross sections on paper. The major axis or length, the minor axis or diameter, and the chords at 10-percent intervals of each semilength beginning with the center of the melon as the origin of the $x$ axis were drawn on each diagram, as shown in figure 3. Next the length of each

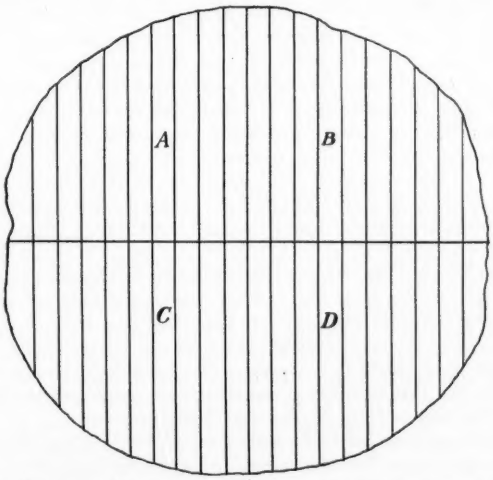


FIGURE 3.—Ordinates at 10-percent intervals of the semilength on a major cross section of a muskmelon fruit. Eighty melons were diagramed by this method to obtain the melon taper curves.

ordinate in all quadrants was measured. In order to eliminate the effect of fruit size, each absolute ordinate was expressed as a percentage of the semidiameter. These relative ordinates at each 10-percent interval of the semilength from all four quadrants were averaged for each melon. These percentages plotted over their corresponding 10-percent intervals are the relative or percentage taper curves of the melons by means of which their shape was compared with the ellipse and circle, the taper curves of the corresponding geometrical solids of revolution. The relative ordinate at the middle of each taper curve was designated the minor form index and used to group the taper curves into more precise shape or form classes.

To determine whether the cross section through the diameter of a melon could be assumed to be a circle for volume computations, the 80 test melons were analyzed as follows. A diagram of each cross section was carefully traced on paper, the long and short diameters were measured, and the difference between the averages was tested statistically. The difference of 5 percent between these average diameters was found to be very highly significant. The minor cross section of a melon is therefore elliptical rather than circular.

To determine whether this difference of 5 percent between the diameters introduced a significant error in the computation of the volume when 2 diameters were averaged, a random sample of 16 melons was analyzed by the following method: The average diameter of each melon was obtained by 2 methods—the long and short diameters were averaged, and also the long diameter and the diameter at right angles to it. The cross sections were then assumed to be circles and the areas corresponding to each of these average diameters were obtained from a table of areas of circles. Next the tracing of each cross section was planimetered twice and the areas averaged to obtain the true area for each melon. The significance of the differences between the true area and these average areas of a circle obtained by the foregoing methods was tested by analysis of variance. The difference between the area corresponding to the area of a circle with a diameter equal to the average long diameter and the one at right angles and the true area was found to be very highly significant; but the difference between the true area and the area of a circle with a diameter equal to the average of the long and short diameters was not significant. It therefore seemed apparent that the area of the cross section through the diameter of a melon could be determined accurately enough for volume computations by averaging the long and short diameters and considering the cross section a circle.

In general the method of analyzing the data was as follows: A preliminary test was made to determine the applicability to melon volumes of the formula $0.5236\ D^2L$, the basic volume formula for an ellipsoid and sphere. The volume of many of the fruits was found to differ significantly from this formula. To determine the causes of such variation, the muskmelon taper curves were compared with the ellipse and circle, the generating curves for these geometrical solids of revolution. The variation of the coefficient of $D^2L$, called the form factor, was investigated for the actual fruits and found to be a linear function of major-form index. The equations for the regression of form factor on major-form index were therefore derived by simple

correlation. The form factors for each major-form index were computed from these equations and these form factors used to set up volume formulas for each major-form class. To facilitate the computation of volumes, a special slide rule and an alinement chart were designed. As a means of determining how well the estimated volumes represented the actual volumes and also to determine whether the estimates from the formulas could be improved, the actual and estimated volumes were compared graphically.

## MUSKMELON TAPER CURVES

The individual percentage taper curves were classified and averaged by arbitrary minor-form index or shape classes. The actual average taper percentages for each minor-form class and also the corresponding percentages for the ellipse and circle are shown in table 1 and in figure 4.

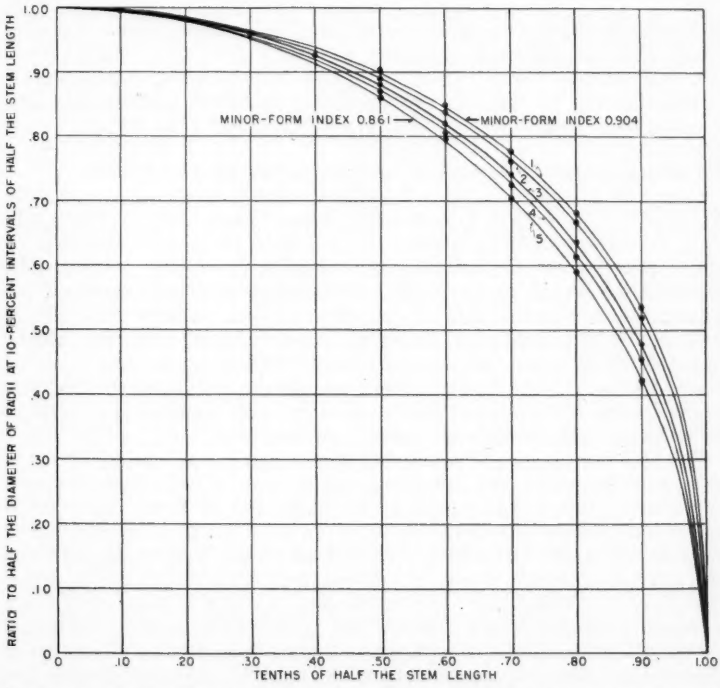


FIGURE 4.—Freehand taper curves to illustrate the general shape and character of the curves for the minor-form index classes.

The ellipsoid and sphere are solids of revolution generated by an ellipse and circle respectively. Therefore muskmelon fruits may be compared with the solids by comparing the formulas of these plane figures with the actual taper curves of the fruits.

TABLE 1.—*Comparison of percentage melon taper curves for different minor-form index classes and percentage taper curve of an elipse and circle*

| Percentage of semilength [1] | Relative taper [2] (percentage of semidiameter) for minor-form index class— | | | | | | Taper for ellipse and circle [3] |
|---|---|---|---|---|---|---|---|
| | 0.850 | 0.860 | 0.870 | 0.880 | 0.890 | 0.900 | |
| | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| 0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 10 | 98.9 | 99.2 | 99.3 | 99.6 | 99.5 | 99.6 | 99.4 |
| 20 | 96.7 | 97.8 | 97.9 | 98.3 | 98.4 | 98.6 | 98.0 |
| 30 | 94.2 | 95.2 | 95.4 | 96.1 | 96.2 | 97.1 | 95.4 |
| 40 | 90.4 | 91.5 | 91.6 | 92.6 | 93.2 | 94.2 | 91.6 |
| 50 | 85.2 | 86.1 | 87.0 | 88.1 | 89.0 | 90.4 | 86.6 |
| 60 | 79.2 | 79.5 | 80.6 | 82.0 | 83.8 | 84.9 | 80.0 |
| 70 | 70.7 | 70.3 | 72.5 | 74.1 | 76.1 | 77.7 | 71.4 |
| 80 | 59.0 | 59.0 | 61.4 | 63.6 | 66.7 | 68.2 | 60.0 |
| 90 | 43.5 | 43.4 | 45.6 | 47.9 | 52.0 | 53.6 | 43.6 |
| | *Number* | *Number* | *Number* | *Number* | *Number* | *Number* | |
| Melons | 2 | 9 | 12 | 27 | 20 | 10 | ---------- |

[1] The percentage ordinates are given for 10-percent intervals of the semilength, beginning with the center of the melon as the origin and the semidiameter at this point as the 100-percent ordinate.
[2] Actual uncurved averages.
[3] The minor-form index of an ellipse and circle is constant, 0.866.

## COMPARISON OF THE SHAPE OF MELONS WITH GEOMETRICAL SOLIDS OF REVOLUTION—THE ELLIPSOID AND SPHERE

The basic formula for both the ellipse and the circle is

$$\frac{y^2}{B^2}+\frac{x^2}{A^2}=1, \text{ or } \left(\frac{y}{B}\right)^2+\left(\frac{x}{A}\right)^2=1 \qquad (1)$$

where $x$ and $y$ are the rectangular coordinates of any point on the perimeter of the plane figure, $B$ is the semiminor axis or one-half the diameter and $A$ is the semimajor axis or one-half the length. When $A$ equals $B$, the two axes are equal and the formula reduces to the equation for a circle. The second form of the equation shows that the sum of the squares of the relative or percentage ordinates and relative abscissas is equal to unity. This fact might have been used to compare the ellipse and circle with the melon taper curves.

The first comparison of interest is the comparison of the minor-form indexes of the melons and the circle and ellipse. If the basic formula (1) is solved for the minor-form index, it will be found to be 0.866 for both the ellipse and circle, as shown in table 1. In other words, the ordinate at one-half the semilength of an ellipse and at one-half the radius of a circle is a constant percentage, 86.6 percent, of the semidiameter. On the other hand, as shown in table 1, the minor-form index of the melons is not constant, but may vary from 0.85 or slightly less than that of an ellipse and circle, to over 0.90, a minor-form index greater than that for the mathematical figures. In other words, the relative ordinates, and therefore the absolute ordinates of some melons, may be more or less than those of an ellipse and circle. In terms of volume, this means that a melon may have more or less volume than a corresponding solid of revolution generated by an ellipse or circle; and, for this reason, the volume formula, 0.5236 $D^2L$, for these solids will not give accurately the volumes of melons unless the formula is modified.

Furthermore, the minor-form index of the melons appears to vary with the major-form index. As shown in figure 5, it increases as a positive linear function of the major-form index. This trend was

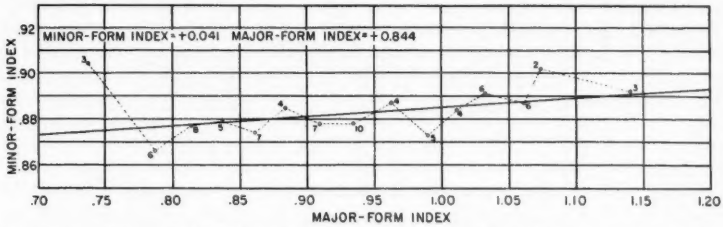


FIGURE 5.—Diagram showing the positive and significant linear correlation between the minor- and major-form index and the equation determined by correlation.

found to be almost highly significant by a statistical test of the correlation coefficient, +0.274. This indicates that such a relationship probably does exist in this sample of fruits. The linear equation for this line derived by simple correlation is

$$\text{Minor-form index} = +0.041 \text{ major-form index } +0.844 \quad (2)$$

Thus as the ratio of the diameter to the length of melon increases, the form, and therefore the volume of melons, increases with major-form index. This necessitates changing the constant, 0.5236, in the volume formula of an ellipsoid for changes in the major-form index of a melon.

To determine whether the melon taper curves were mathematically similar throughout their length to the taper curves of an ellipse and circle, they were compared graphically by the use of logarithmic cross-section paper. If the formula for these geometrical figures is solved for a relative ordinate, it reduces to the form of the well-known parabolic equation, $Y=PX^n$, which plots as a straight line on double logarithmic cross-section paper. The ellipse formula reduced to this type is:

$$\frac{y}{B}=\left[1-\left(\frac{x}{A}\right)^2\right]^{\frac{1}{2}} \quad (3)$$

where $\left[1-\left(\frac{x}{A}\right)^2\right]$ corresponds to $x$ in the parabolic formula and $\frac{1}{2}$ to $n$, and $p$ is equal to 1. If logarithms are taken of both sides of this equation, it reduces to the following linear form:

$$\log \frac{y}{B}=\frac{1}{2}\left\{\log\left[1-\left(\frac{x}{A}\right)^2\right]\right\} \quad (4)$$

The relative taper curves for the melons may therefore be compared with the ellipse and circle by plotting the melon taper percentages $\frac{y}{B}$ in table 1, which correspond to $\frac{y}{B}$ in the formula, over $\left[1-\left(\frac{x}{A}\right)^2\right]$ on double logarithmic cross-section paper. If the melon curves are based

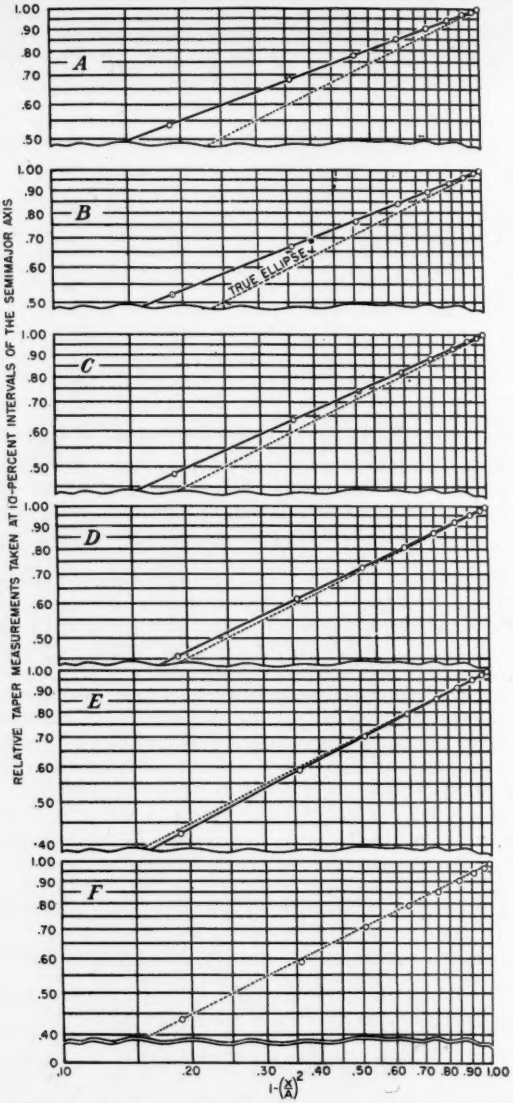


FIGURE 6.—The raw average percentage taper curves of the 80 test melons plotted over $\left[\left(1-\frac{x}{A}\right)^2\right]$ on double logarithmic cross-section paper. The absence of any systematic curvature in these lines shows that they are parabolic curves of the general type, $y=px^n$; and, therefore, the melon curves are members of the same mathematical family of curves to which the ellipse and circle belong. *A*, Minor-form index 0.904, 10 melons; *B*, minor-form index 0.890, 20 melons; *C*, minor-form index 0.881, 27 melons; *D*, minor-form index 0.870, 12 melons; *E*, minor-form index 0.861, 9 melons; *F*, minor-form index 0.852, 2 melons.

on the same type of mathematical equation, they will plot as straight lines.[4]

The actual average taper percentages given in table 1 for each minor-form index class are plotted in this manner in figure 6.

As shown in figure 6, the melon taper percentages for all the minor-form index classes are straight lines. This was also true of a number of the taper curves for individual melons. This graphic test shows that the relative taper curves of melons in this random sample may be represented by the same basic parabolic equation as for the ellipse and circle, as follows:

$$Py=[1-P_x^2]^n \tag{5}$$

where $n$ is the general exponent and also the slope of the line on double logarithmic cross-section paper, and $Py$ and $Px$ are the percentage ordinates and abscissas respectively. Since the slopes of some of these straight lines are less and others greater than the ellipse as shown in figure 6, the exponent $n$ is variable and more or less than one-half.

## DERIVATION OF A VOLUME FORMULA FOR MUSKMELON FRUITS

Derivation of a volume formula from this basic parabolic equation by calculus showed that the variation in the general exponent, $n$, in this basic formula merely varied the coefficient of $D^2L$ in the ellipsoid volume formula, $0.5236D^2L$, but not the exponents of $D$ and $L$.[5] The ellipsoid formula may therefore be generalized for melons by substituting a variable, $K$, called the form factor, for the constant 0.5236.

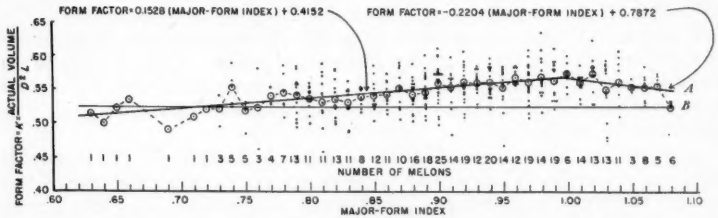


FIGURE 7.—Regression of the form factor, $K$, of the muskmelon volume formula, $KD^2L$, on the major-form index.

The formula may be written as follows: Volume-$KD^2L$. The actual value of $K$ was computed for each fruit by dividing the volume by $D^2L$. Because the minor-form index was found to be a function of the major-form index (fig. 5), $K$ likewise could be expected to be a function of the major-form index. To determine the form of this relationship, $K$ was plotted over the major-form index; and, as shown in figure 7, the trend was found to be a positive linear function up to a major-form index of 1, but above this it was negative. The two correlation coeffi-

[4] BEHRE, C. E. FORM-CLASS TAPER CURVES AND VOLUME TABLES AND THEIR APPLICATION. Jour. Agr. Res. 35: 673–744, illus. 1927.

[5] The variation of the exponents of $D$ and $L$ in the general volume formula, $KD^mL^n$, was investigated by deriving for each major-form class the unknowns $K$, $M$, and $N$ by multiple linear correlation of the logarithms of diameter, length, and volume, but this method was dropped when it was found that the estimates were not enough better to justify the use of the more complex estimating method.

cients, +0.422 and −0.296, were highly significant statistically. Therefore within the limits of this sample, the relationship between the form factor $K$ and the major-form index may be represented by straight lines. The equations for these lines derived by simple correlation are

$$\text{Form factor } (K_1) = +0.1528 \text{ major-form index } +0.4152 \quad (6)$$
$$\text{Form factor } (K_2) = -0.2204 \text{ major-form index } +0.7872 \quad (7)$$

From these equations, the volume formula for each major-form class was obtained. For example, the form factor for the 0.6 form class is (0.1528) (0.6) +0.4152 or 0.5069, and the volume formula for this class is $0.5069D^2L$.

## THE STANDARD ERRORS OF ESTIMATE OF THE FORM FACTOR K AND THE VOLUME

The actual volumes vary from the estimated volumes for several reasons. The average taper curve in one cross section in any one melon may differ from the curve in another cross section. Even within a given cross section, the taper curves may vary from quadrant to quadrant; and the melon, therefore, may not be a perfect solid of revolution. Melons in a given major-form index class may have taper curves that vary from the average for the class. The cross section through the diameter of any individual fruit may be significantly different from the area of the circle or ellipse that corresponds to the average diameter. Different varieties differ in form and therefore in volume. These variations result in errors of estimate for both the form factor K and the volume. The errors of estimate for the equations for $K$ are respectively ±4.5 and ±5.1 percent or approximately ±5 percent. Inasmuch as the volumes are directly proportional to $K$, the average standard error of the computed volume for any individual melon selected at random from 426 should also be ±5 percent. Since very few large flat fruits were available, a reliable estimate of the standard error of this type could not be determined.

Although neither a graphic nor a statistical analysis was used directly to determine whether the form factor varied with the size of the melons within a major-form index class, conclusions may be drawn indirectly from the trends of the lines fitted to the actual volumes plotted over estimated volumes independently classified by diameter, by length, and by volume. If the trends are represented by 45° straight lines through the origin, the form factor does not vary with these variables. As illustrated by figure 8 for two major-form classes, the trends may be represented by this 1 to 1 slope. With the exception of large, very flat melons for which sufficient data were not available, this was also true for the other form classes. Therefore different form factors need not be used for melons with different diameters, lengths, or volumes in the different major-form index classes.

## MELON VOLUME SLIDE RULE

In an effort to facilitate the computation of the estimated volume, an adaptation of an inexpensive wooden slide rule was used. The $D$ scale was used for diameters, the $B$ scale for lengths, and the $A$ scale

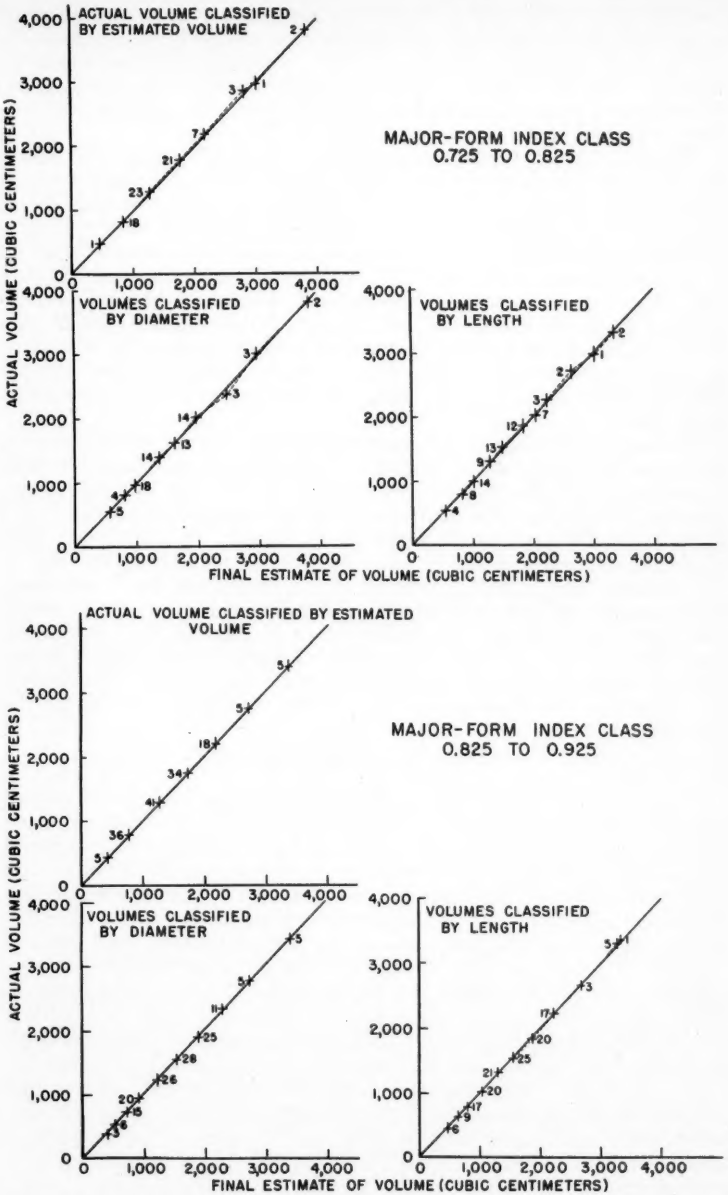
ACTUAL VOLUME CLASSIFIED BY ESTIMATED VOLUME
MAJOR-FORM INDEX CLASS 0.725 TO 0.825
VOLUMES CLASSIFIED BY DIAMETER
VOLUMES CLASSIFIED BY LENGTH
ACTUAL VOLUME (CUBIC CENTIMETERS)
FINAL ESTIMATE OF VOLUME (CUBIC CENTIMETERS)
ACTUAL VOLUME CLASSIFIED BY ESTIMATED VOLUME
MAJOR-FORM INDEX CLASS 0.825 TO 0.925
VOLUMES CLASSIFIED BY DIAMETER
VOLUMES CLASSIFIED BY LENGTH
ACTUAL VOLUME (CUBIC CENTIMETERS)
FINAL ESTIMATE OF VOLUME (CUBIC CENTIMETERS)

FIGURE 8.—Comparison of actual and estimated volumes of muskmelon fruits in two major-form classes.

for volumes. The only modification necessary was the addition of a major-form index scale among the *C* scale divisions. These divisions may be inked with colored ink to distinguish them from the regular *C* scale divisions. Because the divisions for major-form indexes greater and less than 1 overlap, they were also marked with different colored inks.

The form-index scale was inserted by assuming any convenient melon length, such as 20 cm. This length was multiplied by each major-form index, 0.6, 0.7, etc., to obtain the corresponding diameters. Then the form factor, *K*, for each major-form index was computed from formulas 6 and 7. From *K* and the diameters and lengths, a volume for each form index was calculated. Next a scale division was located on the *C* scale for each form index, as follows: The runner was set on the volume on the *A* scale and the length on the *B* scale was brought to the runner; the runner was then set on the diameter on the *D* scale, and under the runner on the *C* scale the division for the given form index was inserted. This was repeated for each major-form index.

The major-form index, the volume, and the density of muskmelon fruits may be computed by determining the length and diameter with the average diameter being taken as midway between the longest and shortest diameters. The major-form index is computed on the *C* and *D* scales by dividing the diameter by the length. The runner is now set to the diameter on the *D* scale and the form index is brought to the runner. The runner is shifted to the length on the *B* scale and the estimated volume is indicated under the runner on the *A* scale. The right index on the rule will have to be reset to the position of the left index when the rule is used to compute the volumes of fruits with diameters and lengths less than 10 cm. To compute the density, the weight of the fruit is divided by the estimated volume on the *C* and *D* scales.

## VOLUME ALINEMENT CHART

A simple alinement chart [6] as illustrated in figure 9 has certain advantages over the slide rule. Errors are less likely to occur since the chart can be easily read by inexperienced individuals. It is a rapid method for computing the volumes from the formula $KD^2L$, especially if *K* is variable. To find the volume of a muskmelon, the diameter and length are measured and the major-form index computed. For example, the major-form index of a melon with a diameter of 9 cm. and a length of 11 cm. is 0.82. A straightedge is placed to intersect the diameter, 9, and the length, 11, as shown by the line *A* in figure 9. While the point of intersection on the dummy axis is held with a pointed instrument, the free end of the straightedge is passed through the major-form index, 0.82, as represented by line *B*. The volume, 480 is read where the straightedge intersects the volume axis. From this volume and the weight of the fruit previously determined, the density is computed, and can be used to indicate the extent of the seed cavity in the fruit.

[6] Bruce D. and L. H. Reineke: Correlation alinement charts in forest research. U. S. Dept. Agr. Bul. 210, 1931.

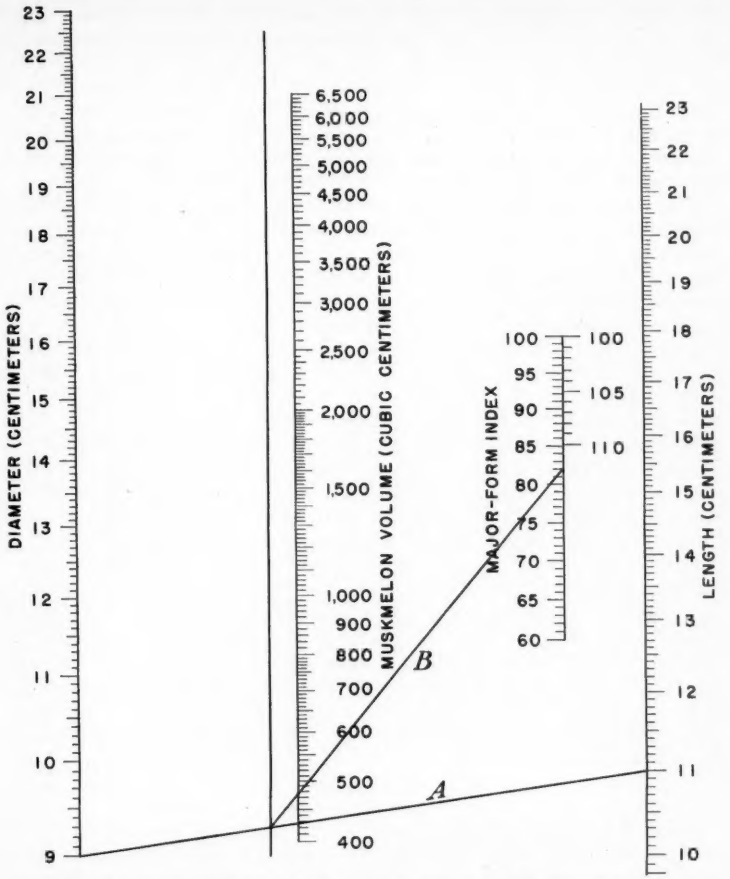


FIGURE 9.—Alinement chart to obtain the volume of muskmelon fruits from length, diameter, and major-form index.

## COMPARISON OF THE ACTUAL AND ESTIMATED VOLUMES

To determine how accurately the formula estimated the volume of melons of different diameters, lengths, and volumes in a given major-form index class, and also to determine whether or not these estimates could be improved, the melons were classified into major-form index classes, 0.625 to 0.724, etc. Within each class, the fruits were grouped into diameter classes irrespective of length and volume, and the actual volumes plotted over the corresponding estimated volume for each diameter class. This process was repeated for both length and volume. With the exception of a few of the largest melons in the highest form class, the trend of the lines was found to be a 45° straight line through

the origin, as shown in figure 9 for two major-form classes. From this it is evident that the average actual volumes are equal to the average estimated volumes for melons of different shapes and sizes. Therefore it seems that no further improvement in the estimates of volume could be obtained for this sample by this estimating procedure. It should, however, be noted that the lack of data for large, flat fruits eliminates any assurance that the chart and slide rule will estimate volumes of this shape and size with sufficient accuracy.

The chart may not estimate volumes of all populations with consistent accuracy. It may, however, be tested and, if necessary, adjusted by the following method: Plot the actual over the estimated volumes for a test sample of not less than 25 fruits, and if the trend may be represented by a 45° straight line through the origin, the chart need not be changed. If it is a straight line other than 45°, the significance of the deviation can be tested by the pairing method, and if the differences are significant, the chart should be changed. In the event that the trend is a curve, the deviation from a 45° straight line may likewise be tested statistically. When the curvature or slope difference is significant, the volume graduations should be modified as follows: If an average actual volume of 456 corresponds to an average estimated volume of 450, the volume graduation, 450, on the chart is labeled 456. By reading additional volumes from the trend lines of actual over estimated volumes, a skeleton series of revised volume divisions are located on the volume axis. To interpolate additional divisions, the vertical distances to these new divisions may be plotted over the new volume graduations and a smooth curve drawn through the points. The revised volume scale is then completed by transferring divisions from this graduating curve. After such revision, the chart should give the desired accuracy for the population from which the sample was taken.

The slide rule may also be modified by relocating the major-form index scale divisions.

## SUMMARY

Since the density of muskmelon fruits indicates the extent of the seed cavity, an attempt was made to develop a mathematical formula to determine the volumes of fruits from a mixture of muskmelon strains. The shape and volume of 426 melons were studied analytically and compared with the shape and volume of an ellipsoid and sphere in order to determine whether the volume formulas for these geometrical solids could be adapted to muskmelon fruits. Volume formulas for melons of different shapes were derived. In order to best utilize the formulas, a slide rule and an alinement chart were designed. A graphic comparison between actual and estimated volumes suggests that the volumes of fruits in the sample were generally estimated with sufficient accuracy.

# SOME ROOT ROTS AND A FOOT ROT OF LUPINES IN THE SOUTHEASTERN PART OF THE UNITED STATES[1]

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## INTRODUCTION

For a number of years agronomists of certain southern agricultural experiment stations have grown three species of lupines (*Lupinus* spp.) experimentally, to determine whether they are suitable for use as winter cover crops. One of these species (*L. angustifolius* L.) is now being grown commercially, more extensively each year. The experimental and limited commercial plantings have brought out the fact that, vigorous as these plants appear to be, they are susceptible to certain diseases. The cause of the most serious of these diseases and the extent of damage to be expected from them have been under investigation for the past 4 years. Two papers by the writer (*17*, *18*),[3] dealing, respectively, with an anthracnose and a botrytis disease, have been published recently. A preliminary report on a fusarium hypocotyl rot was made some time ago (*16*).

These investigations have shown that some of the diseases of lupines in this country are the same as or are very similar to those affecting lupines in other countries. Gould (*5*) has reviewed the literature dealing with certain diseases of lupines in the United States and elsewhere. Other papers, discussing these diseases in foreign countries, have been published by Fischer (*4*), Richter (*10*, *11*), Dippenaar (*3*), Noll (*9*), Carrera and Noll (*2*), and many others. Since a comprehensive review of the literature is available in these papers, no attempt will be made to review it here.

## ROOT ROTS

### GEOGRAPHIC DISTRIBUTION AND ECONOMIC IMPORTANCE

In the spring of 1939 a decay of the roots and hypocotyls of plants of *Lupinus luteus* L. growing in nursery rows at Quincy, Fla., was called to the writer's attention by J. D. Warner.[4] Since that time root rots have been discovered at Gainesville, Fla., Tifton and Americus, Ga., and Auburn, Ala., and have been found to attack *L. albus* L. and *L. angustifolius* as well as *L. luteus*. Similar diseases have been reported from Europe by Richter (*10*), Schultz (*13*), Anagnosto-

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[2] The writer is indebted to George E. Ritchey, of the Division of Forage Crops and Diseases, stationed at Gainesville, Fla., for making observations and sending plant material for study; and to Dr. W. C. Snyder, of the University of California, and Dr. C. D. Sherbakoff, of the Tennessee Agricultural Experiment Station, for assistance in determining the species of *Fusarium* studied.

[3] Italic numbers in parentheses refer to Literature Cited, p. 456.

[4] Agronomist in charge, North Florida Experiment Station, Quincy, Fla.

poulos (*1*), and others, and from South America by Carrera and Noll (*2*).

The wide distribution and severity of root rots, as reported by different investigators, justify the conclusion that they are of considerable economic importance. Where root rots have been observed by the writer, their behavior has been somewhat erratic. For example, they were first observed in severe form at Quincy, Fla., on *Lupinus luteus*, but apparently they have never caused serious damage to *L. angustifolius*, the species grown most extensively there. On the other hand, root rots have killed many or all of the plants of the latter species in some nursery rows at Gainesville, Fla., and at the same time they have caused only slight damage to *L. luteus* at Gainesville. *L. luteus* growing at Americus, Ga., has appeared to be very susceptible, but, so far as observed, commercial fields of *L. angustifolius* grown in south Georgia have as yet suffered only minor losses from root rots.

## METHODS

Isolations and cultural studies were made largely on plain oat agar or 2-percent dextrose-potato agar. Cultures were grown in diffused light at room temperature, usually before a north window. Some of the inoculation experiments were conducted in the greenhouse during the winter months and others out of doors during the summer. The diseases were produced about equally well under both conditions. The soil used for growing the plants was a sandy loam contained in 6-inch pots and sterilized for 3 hours at 25 pounds' pressure. The seeds were immersed for 15 minutes in mercuric chloride (1:1,000) and washed in running water before being planted. Since some of the seed was too old and some too hard, germination was often poor, and consequently the number of plants used in many of the experiments was small, as shown in table 1. The seed or soil was usually inoculated with nodule-forming bacteria from commercial cultures. Inoculations were made by removing the soil from about the plants, usually when they were 1 to 2 inches tall, placing a few grains of oats from flask cultures of the fungus against the hypocotyl, and then replacing the soil. In many cases the fungus used in the inoculations was recovered and in several instances the pathogenicity of the reisolate was proved. Control plants, which were always included in the experiments, were treated in the same manner as the inoculated plants except that sterile oats were used instead of inoculated oats. In only a few instances did infection take place in the control plants, and then the trouble was a damping-off of the seedlings, caused by *Rhizoctonia*.

## SYMPTOMS

Lupine plants affected with root rots vary somewhat in appearance. Dwarfing and often yellowing, followed in late stages by wilting and slow death, are characteristic of the top symptoms. The hypocotyl and roots show a dry rot that ranges in color from water-soaked to straw-colored, mahogany red, chestnut, chocolate, and almost black,[5] depending on the stage of development, the moisture content of the tissue, the host species attacked, and the causal agent. At first only a small superficial reddish or brown lesion appears on the affected part, but this may spread until the entire underground part of the plant is

[5] Insofar as practicable, all color names are those given by Ridgway (*12*).

involved and the plant is greatly dwarfed or wilts and dies. These diseases are not typical fusarium wilts, although wilting does occur as a result of the severance of the hypocotyl or the destruction of the root system.

Inoculation experiments have shown that several fungi cause rotting of lupine roots and the symptoms vary somewhat, as stated above. Additional descriptive notes will appear under the discussion of the inoculation experiments.

## ETIOLOGY

Root rots of lupines can be caused by several different fungi, largely *Rhizoctonia solani* Kühn and species of *Fusarium*. Only a limited number of plants were available for making isolations, and it is thought that more fungi may be involved in this disease complex than are discussed here. This is suggested by the number of root-rotting fungi described by other investigators and also by the fact that fungi not isolated from lupines produced infection, as will be brought out later.

### RHIZOCTONIA SOLANI

*Rhizoctonia* has been isolated only occasionally from naturally infected plants from the field and then it was associated with one or more species of *Fusarium*. Inoculation experiments have shown that this fungus is capable of causing a rapid decay of the hypocotyl of young lupine plants. The following experiments are typical.

On July 11, 1941, 12 seedlings of *Lupinus luteus* about an inch tall, growing out of doors in sterilized soil in 6-inch pots, were inoculated with *Rhizoctonia* originally isolated from *L. albus*. On July 14, 10 of the 12 plants inoculated were nearly dead and the underground parts were all badly decayed (fig. 1). The affected tissue was soft and water-soaked or light brown in color. Microscopic examination showed the decayed tissue to be permeated with large vigorous strands of *Rhizoctonia* mycelium. None of the control plants were affected. *Rhizoctonia* caused a typical damping-off of these plants in 3 days. Six plants of *L. angustifolius* were inoculated in the same manner at the same time. All 6 became infected, 2 being dead and the others more or less decayed on July 25. Seedlings of this species did not succumb so rapidly as did those of *L. luteus*. In like manner 10 plants of *L. albus* were inoculated on July 14, and 9 were nearly dead on July 25. In no case did the controls become infected. In other experiments, where older plants were inoculated, there was little or no infection. The results of the experiments lead to the conclusion that *Rhizoctonia* is potentially capable of causing a serious damping-off of seedlings but usually is not a very active parasite of older plants. Of course, under extremely favorable environmental conditions, the fungus might cause considerable damage to older plants.

### FUSARIUM SPP.

Several different species of *Fusarium* cause root rots of lupines in other countries (*2*), and the work reported here shows that this is true also in the United States. In fact, the lupines are so commonly attacked by fusaria that it is difficult to determine which species most often acts as the primary parasite and which as the secondary invader. Over a period of several years, however, *Fusarium oxy-*

FIGURE 1.—Hypocotyl rot of *Lupinus luteus* seedlings, resulting from inoculation with a pure culture of *Rhizoctonia solani*. The decayed tissue was soft and had a water-soaked or light-brown color, in contrast to the red color of the dry rot caused by most species of *Fusarium*. Photographed 3 days after inoculation. × 1.

TABLE 1.—*Infection resulting from the inoculation of 3 species of lupines with various isolates of Fusarium from decaying lupine roots from different sources*

| Isolation No. | *Lupinus albus* plants | | | *Lupinus luteus* plants | | | *Lupinus angustifolius* plants | | | Species of *Fusarium* | Source of isolate |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Inoculated | Infected | | Inoculated | Infected | | Inoculated | Infected | | | |
| | *Number* | *Number* | *Percent* | *Number* | *Number* | *Percent* | *Number* | *Number* | *Percent* | | |
| 1123E | 8 | 0 | 0 | 9 | 6 | 66.7 | | | | *F. oxysporum* f. *radicis-lupini.* | Gainesville, Fla. |
| 1123E | 7 | 0 | 0 | 4 | 2 | 50.0 | | | | do | Do. |
| 1135B | 9 | 5 | 55.6 | 7 | 2 | 28.6 | | | | do | Do. |
| 1135B | 9 | 0 | 0 | 2 | 2 | 100.0 | | | | do | Do. |
| 1228C | 2 | 0 | 0 | 1 | 1 | 100.0 | | | | do | Do. |
| 1141D | 10 | 8 | 80.0 | 7 | 6 | 85.7 | | | | do | Quincy, Fla. |
| 1141D | 8 | 1 | 12.5 | 7 | 3 | 42.9 | 19 | 9 | 47.4 | do | Do. |
| 1141E | 9 | 3 | 33.3 | 9 | 2 | 22.2 | | | | do | Do. |
| 1169E | 10 | 3 | 30.0 | 8 | 7 | 87.5 | | | | do | Reisolate of 1141D. |
| 1202C | 8 | 2 | 25.0 | 7 | 0 | 0 | | | | do | Do. |
| 1231C | 7 | 7 | 100.0 | 5 | 5 | 100.0 | 19 | 16 | 84.2 | do | Americus, Ga. |
| 1180 | 10 | 9 | 90.0 | 8 | 6 | 75.0 | | | | do | Cotyledons. |
| 1203 | 9 | 8 | 88.9 | 6 | 6 | 100.0 | | | | do | Reisolate of 1180. |
| 1237B | 9 | 5 | 55.6 | 0 | | | | | | do | Tifton, Ga. |
| 1238A | 6 | 6 | 100.0 | 3 | 2 | 66.7 | | | | *F. moniliforme* | Auburn, Ala. |
| 1238B | 9 | 9 | 100.0 | 3 | 3 | 100.0 | 19 | 17 | 89.5 | do | Do. |
| 1229A | 10 | 10 | 100.0 | 4 | 4 | 100.0 | 18 | 17 | 94.4 | *F. solani* f. *lupini* | Gainesville, Fla. |
| 1240 | | | | 3 | 3 | 100.0 | 17 | 17 | 100.0 | *F. solani* f. *pisi* | Experiment, Ga. |
| 1240 | | | | 22 | 13 | 59.1 | | | | do | Do. |

*sporum* Schlecht. has been isolated most frequently from lupines collected by the writer or sent to him by others. Some isolates proved to be virulent pathogens, others weak ones, and still others were nonpathogenic. Isolations have been made from diseased hypocotyls of lupine plants of different ages and from various sources. Several of the isolates have been pure-lined and used for cultural and inoculation studies. The results of some of the inoculation experiments are summarized in table 1. Three different species of *Fusarium* isolated from lupine proved to be pathogenic, namely, *F. oxysporum*, *F. moniliforme* Sheldon, and *F. solani* (Mart.) Appel and Wr. The results of the studies with these will be discussed separately.

### FUSARIUM OXYSPORUM

The data in table 1 show that the isolates of *Fusarium oxysporum* from diseased plants from Gainsville, Fla., possessed different degrees of pathogenicity, seemingly being more pathogenic on *Lupinus luteus* than on *L. albus*. Isolates of the same fungus obtained from Tifton and Americus, Ga., also proved to be pathogenic (fig. 2). Cultures obtained from *L. luteus* from Quincy, Fla., proved to be pathogenic on all three species of lupines in the several tests made. In some instances a fairly high percentage of infection was obtained in one species of lupines and little or none in the others. Cultures 1169E and 1202C, which were reisolates of 1141D, and culture 1203, a reisolate of 1180, were all more or less pathogenic, as were the original isolates. Culture 1180 was isolated from cotyledons of *L. albus* after the seedlings were up but before the seed coat had pulled away from the cotyledons. The fact that this isolate was pathogenic indicates that the fungus was seed-borne. If this fungus is seed-borne, it might account for its wide distribution in a territory where lupine culture has just started.

Of 115 *Lupinus albus* plants inoculated with *Fusarium oxysporum*, 44.3 percent were infected (table 1). The same fungus infected 60 percent of the *L. luteus* plants and 65.8 percent of the *L. angustifolius* plants inoculated. These values do not suggest any marked difference in the susceptibility of the different species. The only explanation of the great variation in the amount of infection obtained in the different experiments seems to be that the fungus is very sensitive to environmental conditions. When conditions are very favorable it is highly pathogenic, but when they are less favorable it is only weakly pathogenic or not at all. This possible explanation is supported by field observations. In some years and under some local conditions this root rot is very destructive, whereas in other years there is little disease or the disease, though present, is of little economic importance.

The nature of the lesions caused by the fungus on *Lupinus luteus* is shown in figure 2. The consistent origin of the lesions on the hypocotyl is due to the fact that the inoculum was placed against the plant just below the surface of the soil and not because that part of the plant is necessarily more susceptible. Figure 2, *E*, shows that the entire root system as well as the hypocotyl may be destroyed. The figure also illustrates the fact that dwarfing of the plants and shriveling and dying of the leaves do not become conspicuous until the hypocotyl or root system is badly decayed. Figure 3 shows the same type of symptoms produced on *L. albus* by this fungus

(1231C, isolated from a plant collected at Americus, Ga.). There was no dwarfing in the two plants shown in figure 3, *A* and *B*, but another plant was considerably stunted (fig, 3, *C*). The plants were photographed 15 days after inoculation. Sometimes the fungus continues its activity until the entire root system is destroyed and

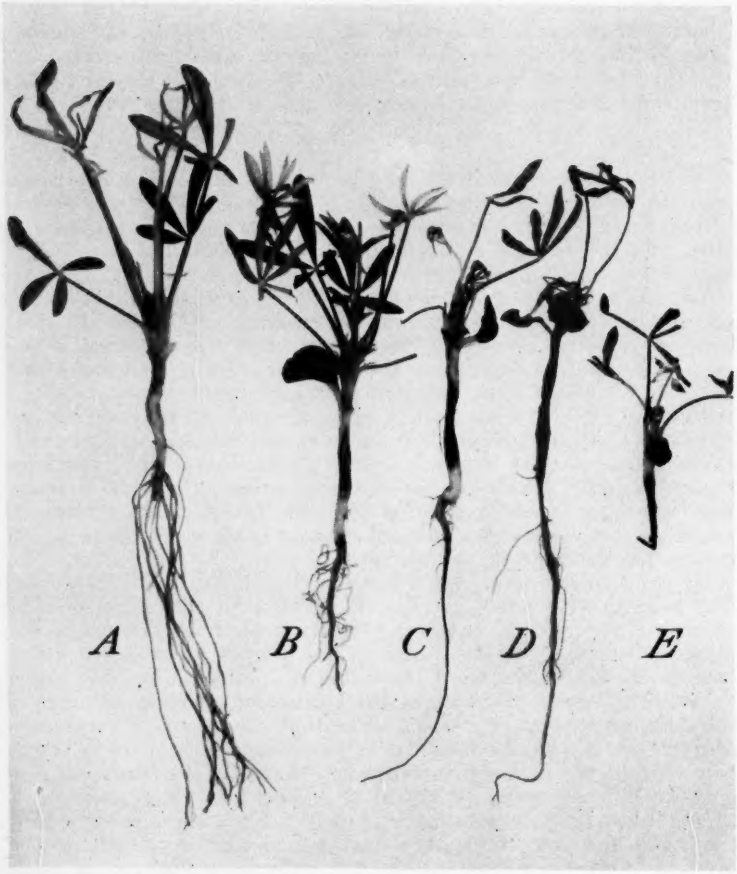


FIGURE 2.—Hypocotyl rot of *Lupinus luteus* plants, resulting from inoculation with *Fusarium oxysporum* f. *radicis-lupini*: *A*, Uninoculated control; *B* to *E*, plants showing various degrees of decay, from slight canker (*B*) to complete destruction of root and lower stem (*E*). × ⅜.

the plant is killed; at other times it produces only a shallow lesion, after which it ceases its activity and the decayed tissue cracks, owing to the growth of the tissue beneath, and much of it sloughs off. At first only the cortex is attacked, but if conditions are favorable for the continued action of the fungus the vascular region is invaded and may be entirely decayed (fig. 2, *E*).

The roots and hypocotyls of naturally infected plants show all

stages of decay, from very slight superficial lesions to complete severance of the underground parts at some point or the entire destruction of the fibrous root system. The coloring in the decaying tissue resulting from natural infection, like that due to artificial

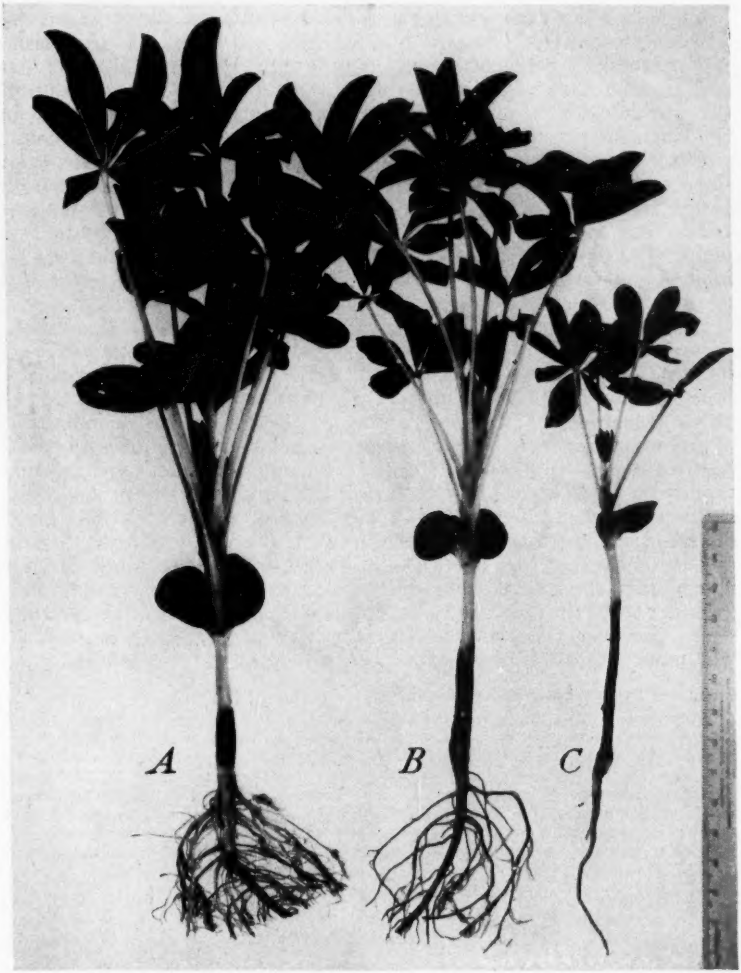


FIGURE 3.—*Lupinus albus* plants showing cankers characteristic of root rot caused on this host by *Fusarium oxysporum* f. *radicis-lupini: A* and *B*, No dwarfing or wilting present; *C*, considerable dwarfing and decay of hypocotyl but no wilting. ×½.

inoculation, varies considerably, but, as already stated, it is some shade of red or brown. The rate at which the fungus spreads through the tissues varies greatly in both naturally and artificially infected plants. Under field conditions, infected plants may be killed in

the seedling stage or may die at any time during the growing season. Some plants may live and mature seed, even with more or less of their root system destroyed. A stand of plants may appear entirely normal, so that the presence of the disease is not suspected until some plants are pulled and the roots examined.

There is some variation in the isolates of this species of *Fusarium*. The isolate most commonly obtained from naturally infected plants is *F. oxysporum* Schlecht. emend. Snyder and Hansen (*14*).[6] Snyder and Hansen have pointed out that there is such a wide variation in the physiological reactions, types of sporulation, and spore size in the single-spore isolates from cultures of fusaria that it hardly seems worth while to include here any detailed data of that sort. However, since some workers may wish to have a clearer idea of the relation of the fungi studied by the writer to the species listed by Wollenweber and Reinking (*19*), the following statement of Snyder [7] is included: "Since it [fungus 1141D] fails to produce sporodochia it might be placed according to the Wollenweber system in *F. orthoceras* or thereabouts."

Since this fungus belongs to the species *Fusarium oxysporum*, according to Snyder and Hansen's classification, and is parasitic on lupines, it should be designated by the form name of the host, namely, *lupini*. However, this form name has already been applied (*14*, *p. 66*) to a member of this species that produces a typical vascular wilt of lupines in Europe. The fungus considered herein produces a typical root rot and not a vascular wilt. It is true that some fusarium-wilt-producing fungi may cause a certain amount of root rot and that the wilt-producing fungi do not always pass up the stem for any great distance. Perhaps the difference between the wilt-producing fusaria and those causing root rot is one of degree rather than kind. If this is true, then the fungus under discussion may be called *F. oxysporum* f. *lupini*. Until further study has shown that these are intergrading forms, however, the writer feels that a different form name is justified. The name *Fusarium oxysporum* f. *radicis-lupini* n. f. is proposed.

**Fusarium oxysporum** f. **radicis-lupini** n. f.

Microconidia abundant, macroconidia usually few, typically three-septate, straight or slightly curved; nonseptate, 5$\mu$–13$\mu$ ×3$\mu$–4$\mu$ (average 9$\mu$×3.5$\mu$); one-septate, 11$\mu$–22$\mu$×3$\mu$–4$\mu$ (average 14.5$\mu$×3.6$\mu$); two-septate, 17$\mu$–20$\mu$×3.5$\mu$–4$\mu$ (average 18$\mu$×3.7$\mu$); three-septate, 17$\mu$–33$\mu$×3.5$\mu$–4.0$\mu$ (average 24.5$\mu$×3.8$\mu$). Aerial mycelium usually well developed; at first white; later, on old oatmeal-agar slants, dull dusky purple to dark napthalene violet. Pionnotes and sporodochia absent, no sclerotia seen. Chlamydospores abundant, terminal or intercalary, globose to pear-shaped, smooth or roughened, mostly one-celled, sometimes two-celled. One-celled, 6$\mu$–10$\mu$×3.5$\mu$–7.5$\mu$ (average 7.7$\mu$×6.3$\mu$). Causes a root rot of *Lupinus* spp. in the southeastern part of the United States.

### FUSARIUM MONILIFORME

*Fusarium moniliforme* [8] was isolated several times during the course of these investigations, and the results presented in table 1 show that it was pathogenic under the conditions of the experiment. The isolates tested gave a rather high percentage of infection in all three host species used. Figure 4 shows cankers produced on hypocotyls of *Lupinus angustifolius*.

[6] Determined by Dr. W. C. Snyder.
[7] In a letter to the writer.
[8] Identified by Dr. D. C. Sherbakoff.

The plants were inoculated in the usual manner on October 29, 1941, and photographed on January 13, 1942. The fungus was recovered from several of the lesions. The writer doubts that this fungus is responsible for any large proportion of the root rotting of lupines observed in the field. Nevertheless, the fungus is widespread and is capable of attacking all three host species. It might, therefore,

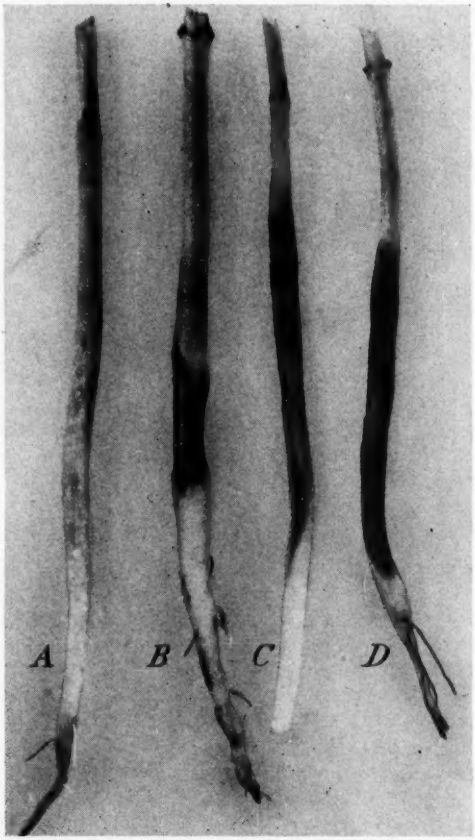


FIGURE 4.—Cankers produced by *Fusarium moniliforme* on hypocotyls of *Lupinus angustifolius: A*, Uninoculated control; *B* to *D*, cankers of various sizes. Photographed about 10 weeks after inoculation. × 1.

under conditions favorable for rapid development, cause considerable damage. The lesions produced by this fungus under experimental conditions were straw-colored and not very deep, but otherwise differed little from lesions caused by the other fusaria.

### FUSARIUM SOLANI

A single plant of *Lupinus angustifolius*, growing in a greenhouse at Gainesville, Fla., was found to be suffering from a root rot, and

*Fusarium solani*[9] was isolated from it. Inoculation experiments showed this fungus to be pathogenic on all three species of the host, as denoted by the figures for the culture 1229A in table 1. Figure 5 shows four plants of *L. albus* with cankers of various sizes resulting from inoculations made just 2 weeks earlier. None of the control plants were affected. The lesions could not be distinguished from those caused by *F. oxysporum* f. *radicis-lupini*, but the rate of decay

FIGURE 5.—Plants of *Lupinus albus* (*A–D*), showing various degrees of injury, from very small canker (*A*) to destruction of entire root system (*C*, *D*). Inoculated with *Fusarium solani* f. *lupini* September 9, 1940; photographed September 23, 1940. × ⅝.

was slightly more rapid and the affected tissue was darker in color. There was no wilting of the foliage until the root system was badly decayed. Figure 5, *C* and *D*, illustrates the amount of dwarfing. Figure 5, *B*, shows a large lesion on the hypocotyl, yet the plant was only slightly, if at all, dwarfed.

Since the causal fungus belongs to the species *Fusarium solani*[10]

[9] See footnote 8, p. 448.
[10] Identification confirmed by Dr. W. C. Snyder

and is pathogenic to *Lupinus*, this fungus becomes *F. solani* f. *lupini* n. f. A brief description is given below. This fungus would probably be classed as a variety of *F. solani* in the Wollenweber and Reinking (*19*) system of classification.

**Fusarium solani f. lupini n. f.**

Macroconidia abundant, forming sporodochia and pionnotes. Spores from pionnotes on 2-percent dextrose-potato agar slants: Nonseptate, 9$\mu$–15$\mu$ × 4$\mu$–5.5$\mu$; one-septate, 17$\mu$–23$\mu$ × 5$\mu$–5.5$\mu$; two-septate, 25$\mu$ × 6$\mu$; three-septate, up to 99 percent, 25$\mu$–43$\mu$ × 5$\mu$–6$\mu$ (average 35.9$\mu$ × 5.6$\mu$). Sporodochia and pionnotes abundant, light brown approaching clay color, sometimes olive buff. Spores slightly curved, nearly uniform in diameter, tapering abruptly at one or both ends or often rounded at ends. Sometimes distinctly wider above or below the middle. Found causing a root rot of *Lupinus angustifolius* in the greenhouse at Gainesville, Fla.

While working on lupine root rots, the writer isolated a fungus (1240) from a hybrid pea plant (*Pisum arvense* L.) on which it was evidently causing a root rot. Since this fungus seemed to be very similar to that from lupines (1229A), its pathogenicity was tested. As indicated in table 1, it was pathogenic on both *Lupinus luteus* and *L. angustifolius*. When inoculated into Austrian Winter peas, it caused a mild type of root rot and was recovered from several of the plants. Since it is of the *Fusarium solani* type and is pathogenic to peas, it is classed as *F. solani* f. *pisi* (Jones) Snyder and Hansen.

The strain studied differs from that described by Jones (*7*) chiefly in spore size. The three-septate spores from pionnotes from 2-percent dextrose-potato agar slants, grown in a north light at room temperature (ranging from 25° to 30° C. most of the time), measured 29$\mu$–47$\mu$ × 5$\mu$–6.5$\mu$ (average 39.2$\mu$ × 6$\mu$). Jones gives 27$\mu$–37$\mu$ × 4$\mu$–4.5$\mu$ (average 31.7$\mu$ × 4.3$\mu$) as the size of the three-septate spores of *Fusarium martii* var. *pisi* that he studied. The writer's spore measurements fall well within the limits given for this species by Harter (*6*) so far as length is concerned. Harter made no study of the variation in spore width. He, as well as Snyder and Hansen (*14*, *15*), points out that considerable variation may be expected in spores of these fungi, and this is probably the explanation for the apparent discrepancy between these two sets of spore measurements.

### Pythium graminicolum

Several species of *Pythium* have been found to be associated with lupine root rots in other countries (*13*). None has been isolated from naturally infected lupine roots in the work reported here. A single experiment was conducted, however, to test the pathogenicity of 2 species of *Pythium* and 1 of *Aphanomyces*, since these cause root rots of other legumes. Both *Lupinus albus* and *L. luteus* were included in the experiment. *Pythium irregulare* Buisman and *Aphanomyces euteiches* Drechs. failed to produce any appreciable decay in the hypocotyls or fibrous roots of lupines. The inoculations were made on September 12, 1940, and 1 week later 13 out of 20 plants of *L. albus* and 1 out of 5 plants of *L. luteus* inoculated with *P. graminicolum* Subr. were diseased. The nature of the injury is illustrated in figure 6. The decayed tissue toward the ends of the lesions approached a chestnut color when moist, while that nearer the center was darker, being almost black in places. The cells contained many large strands of typical *Pythium* mycelium. The fungus was recovered from the

diseased tissue. This experiment suggests that *Lupinus albus* may be quite susceptible to *Pythium graminicolum* under conditions suitable for the latter's development. Although 1 plant of *L. luteus* developed a typical lesion, the others remained entirely healthy.

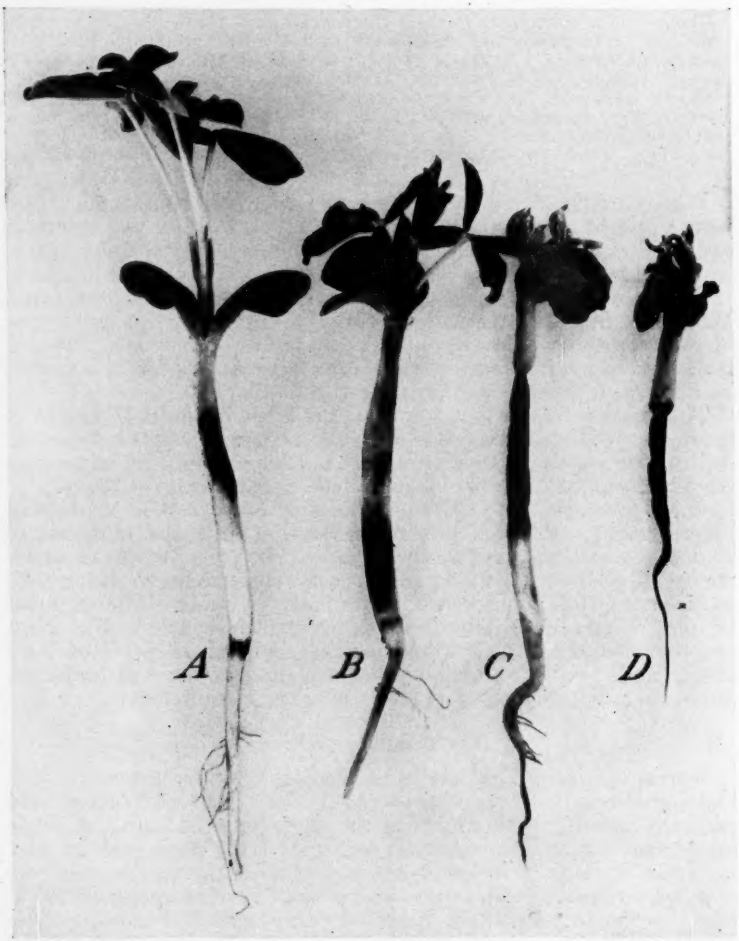


FIGURE 6.—Hypocotyl rot of *Lupinus albus*, caused by *Pythium graminicolum*: *A*, Plant not dwarfed as compared with controls; *B* to *D*, plants considerably smaller and about to die. Inoculated September 12, 1940; photographed 8 days later. × ⅗.

## FOOT ROT

### SYMPTOMS

Next to the root rots, the most common and destructive disease of lupines studied is a foot rot caused by *Sclerotium rolfsii* Sacc. This fungus produces a characteristic foot rot of lupines just as it does on

so many other plants in the South. The plants are attacked near the surface of the soil, where a lesion is formed that gradually involves the entire stem and often girdles it. The plants may at first be stunted, but later they wilt and die. Often more or less white mycelium is seen growing over the surface of the soil about the plant. Typical small, round, white sclerotia, that later turn brown, are frequently formed on the lesions or on the soil adjacent, especially in wet weather. Plants of all ages growing in the field may be killed during the spring and early summer. Often a number of neighboring plants, or consecutive plants down a row, are attacked, although isolated plants also may be killed. Sometimes a considerable number of plants in a field may succumb to the disease, but, so far as the writer's observations go, usually only isolated or small groups of plants are affected. The

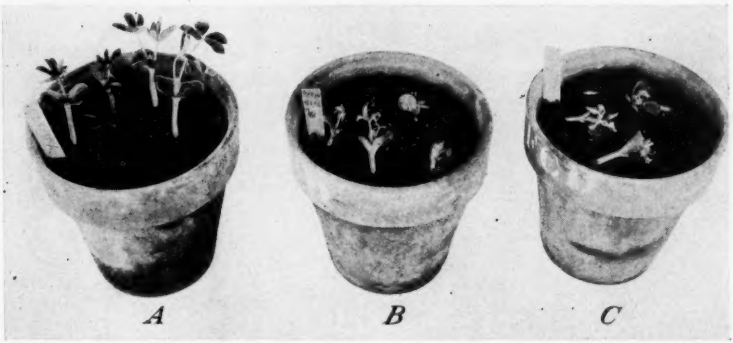


FIGURE 7.—Seedlings of *Lupinus albus: A*, Uninoculated controls; *B* and *C*, all plants decayed at the surface of the soil and fallen over, 4 days after being inoculated with *Sclerotium rolfsii*. × 3/15.

total percentage of plants lost in a small patch at times may be high. Young seedlings may be decayed off and die within a few days, but death comes much more slowly to older plants.

### INOCULATION EXPERIMENTS

The causal fungus was isolated and inoculation experiments were conducted in much the same manner as described under root rots. The chief differences were that the medium was an agar culture and sclerotia were used as the inoculum. Figure 7 shows seedlings of *Lupinus albus* decayed off near the surface of the soil 4 days after inoculation. The nature of the lesions produced by this fungus is more apparent in the plants illustrated in figure 8. This fungus penetrated the stem and severed it rather quickly. The fungus works up and down the stem also, especially when the stem is less succulent, and involves a considerable portion of it. The seedlings illustrated in figure 8 were inoculated by placing hyphae from an agar culture directly against the healthy hypocotyl. The affected tissue was water-soaked to light brown in appearance.

The fact that fully grown plants are killed suggests that plants are susceptible at all ages, but it was not known definitely when the older plants became infected. A single experiment was conducted to gain

further information on the susceptibility of older plants. *Lupinus angustifolius* plants 1 foot tall and *L. luteus* plants 4 to 5 inches tall were

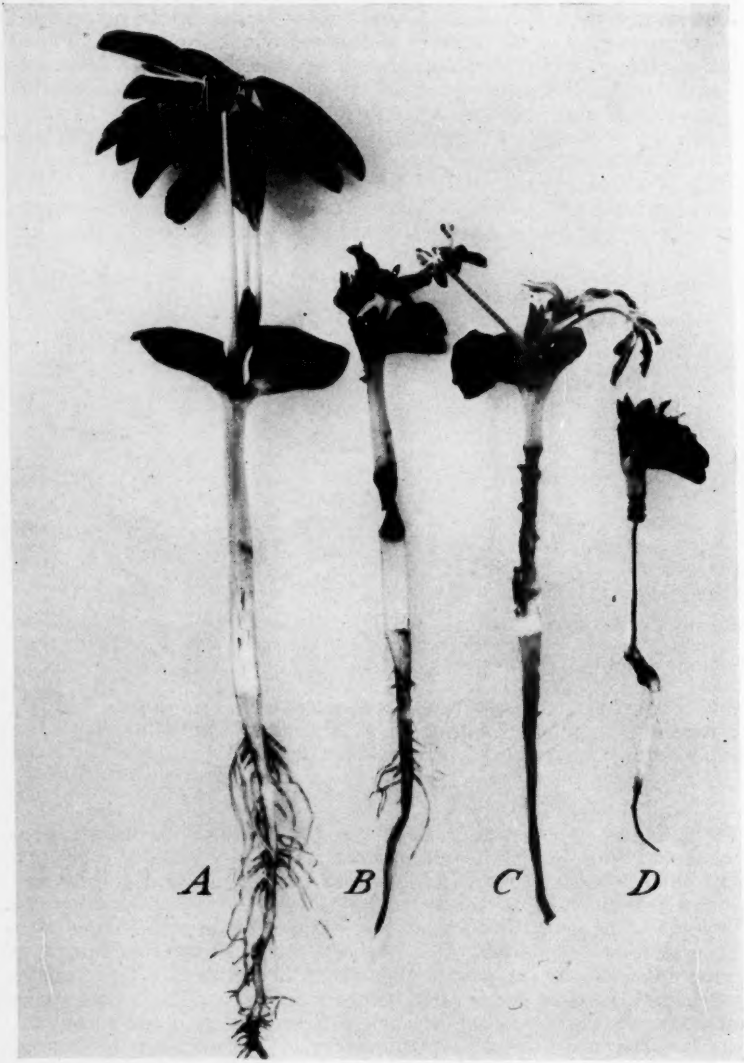


FIGURE 8.—*Lupinus albus* seedlings. *A*, Uninoculated control. *B* to *D*, Plants inoculated with *Sclerotium rolfsii*, showing injury and dwarfing: *B*, Stem almost completely severed 12 days after inoculation; *C* and *D*, the fungus has worked up and down the stem from the original point of infection. × ½.

inoculated by placing sclerotia against the stems just below the surface of the soil. In order to give the fungus a better opportunity to get

started, some potato starch was placed on and about the plant and sclerotia. The inoculations were made May 3, 1939; on June 7, 3 out of 16 *L. luteus* plants inoculated had characteristic *Sclerotium rolfsii* lesions at the point of inoculation, and 8 out of 11 *L. angustifolius* plants were infected. One plant of the latter had been killed and the others had well-developed cankers. The lesions varied in color but were close to the Mars brown or the Vandyke brown of Ridgway (*12*). The diseased tissue adjacent to the healthy tissue was often liver brown in color. The lesions were sunken and had numerous strands of white aerial mycelium on the surface. There was little evidence of top symptoms until the stem was nearly girdled, and then the plant wilted and died rapidly.

## DISCUSSION

The fact that a form of *Fusarium oxysporum*, belonging to the *orthoceras* group under the Wollenweber classification, was found to cause a root rot of lupines in the southeastern part of the United States is not surprising in view of the fact that Carrera and Noll (*2*) found what appears to be the same fungus pathogenic to certain species of lupines in Uruguay. They rate this fungus as possessing medium virulence. In the present work the amount of infection produced by this fungus in the different experiments varied so much that it would be difficult to rate its virulence precisely. Perhaps the fact that the amount of infection did vary would justify classing it as having medium virulence, as did Carrera and Noll, although under certain field conditions, it does appear to have a high degree of virulence. Noll (*9*) isolated several species of *Fusarium* from lupine roots, *F. oxysporum* and *F. solani* being the commonest. He states, however, that *F. orthoceras* was also pathogenic.

The question whether *Fusarium oxysporum* f. *radicis-lupini* causes a root rot or a wilt may be open to debate. The statement was made earlier in this paper (in the section on symptoms) that the disease studied was not a typical fusarium wilt, although wilting does occur as a result of the severance of the hypocotyl or the destruction of the root system. No extensive histological studies were made, but the stems of a number of plants were sectioned. The central vascular system often is somewhat discolored and some gum is present in the tissues above the region in which the cortex is seriously damaged or destroyed. Some mycelium may also be present a short distance above the decayed tissue. Carrera and Noll discussed this subject in considerable detail and concluded to call the disease caused by the species of *Fusarium* investigated by them root rot and wilt.

In general, a fusarium wilt disease is characterized by a browning of the vascular bundles, often accompanied by wilting. There may or may not be root rot present, especially in late stages of the disease; but, if present, it is commonly caused, or at least accentuated, by secondary invaders. As already pointed out, the typical symptoms of the lupine disease under discussion are a decaying of the roots and not a vascular browning. For this reason the writer prefers to consider this disease a root rot rather than a wilt. It is pertinent to note, as pointed out by Wollenweber and Reinking (*19*), that there is in Europe a typical wilt attributed to a form of *Fusarium oxysporum*, as well as root rots of lupines caused by *F. avenaceum* (Fr.) Sacc. and *F. equiseti* (Cda.) Sacc.

It is evident from these investigations that root rots of lupines in the United States are caused by several fungi. Fusaria are probably the most destructive. *Rhizoctonia* is thought by some investigators to be the most virulent pathogen attacking lupines. This may be true of plants in the seedling stage, but the evidence presented in this paper does not justify such a conclusion for older plants. It is true, however, that strains of *Rhizoctonia* differ considerably in pathogenicity (*8*), and the strain used in these investigations may not have been so virulent as some.

Schultz (*13*) points out that many species of *Pythium* cause rotting of lupine roots in Germany. Of the species tested in the present investigations, only *P. graminicolum* proved to be pathogenic. No *Pythium* was isolated from naturally infected plants, but too few isolations were made to justify the conclusion that *Pythium* does not contribute to the destruction of lupine seedlings in this country. Some seedsmen have reported that it is necessary to sow lupine seeds much thicker than would otherwise be necessary, because of the high mortality of the seedlings. The writer has made no specific investigation into the cause of the death of these seedlings, but it is assumed that *Rhizoctonia*, the fusaria, and possibly some species of *Pythium* may be the causal agents.

Although the losses caused by these diseases have been serious in local areas, largely in experimental plots, no general complaint has been received from commercial growers, a fact which indicates that losses have not been large or that their cause has not been recognized. Since there appear to be so many potential causal agents of root rots, and since all are soil-borne and some live on other hosts, finding resistant strains or species of the host is probably the only hopeful control measure.

## SUMMARY

Root rots of three introduced species of lupines (*Lupinus angustifolius*, *L. luteus*, and *L. albus*), caused by several species of *Fusarium*, by *Rhizoctonia solani*, and by *Pythium graminicolum*, and a foot rot caused by *Sclerotium rolfsii* are described and illustrated.

*Fusarium oxysporum* f. *radicis-lupini* n. f., the pathogen most frequently isolated, is believed to be the common cause of the root rotting of lupines found in the southeastern part of the United States. *F. solani* f. *pisi*, *F. solani* f. *lupini* n. f., and *F. moniliforme* also are shown to be pathogenic under the conditions of these experiments.

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